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Development of Shared Mental Models for Submarine Officers

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SUMMARY PAGE

Problem: Experts in many domains possess and utilize mental models that novice personnel have not yet developed. As people gain more experience, their mental models tend to become more homogeneous with other experts, compared to the novice people. Towards this end, system developers and training researchers attempt to identify critical components of expert operator assessment and knowledge. Via analyses of submariner knowledge for concepts related to responsibilities for the Officer of the Deck (OOD) task, this study examined how training may alter knowledge representation and priority of conceptual importance and how overlap in mental models may be due to amount of experience.

Method: Eighty-three Naval Officers performed a card sorting and ranking task to indicate similarity and relative importance among 20 categories of information available on submarines in different operational environments. These submarine concepts consisted of types of information the submarine OOD would encounter while on watch, with the exception of tactics information. Participants were instructed to sort the cards into piles according to similarity and were not constrained by the number of piles they could create. Following the sorting task participants ranked the cards according to relative importance for four scenarios. They were instructed to create a single pile of cards ordered from the most important piece of submarine information to the least important. Data were collected from Submarine Officer Basic Course students pre and post course, Submarine Officer Advanced Course students, and Post Department Head submariners.

Findings: In support of shared mental model theory and consistent with other studies of knowledge organization and the mental models of submariners, this investigation found that more experienced personnel view conceptual linkages more similarly and showed higher agreement with an expert model (Fiore, Fowlkes, Martin-Milham, & Oser, 2000). Conversely, the least experienced personnel see conceptual linkages less similarly, but, following training, these participants were found to view the conceptual linkages more similarly to the experienced personnel. From the standpoint of understanding the importance of particular concepts, significant differences between experienced and novice personnel were identified prior to, and following, training. These data highlight how participants vary in their understanding of the importance of these concepts.

Application: Knowledge of the mental models that experienced submarine officers possess can provide input into training objectives for less experienced personnel. Moreover, knowledge of how experienced submariners place priority on certain information items in different situations can guide training for submariners early in their career.

ADMINISTRATIVE INFORMATION

This work was conducted under Work Unit 51001 entitled: "Information Requirements and Information Organizations in Submarine Combat Systems." The opinions or assertions contained herein are the private ones of the authors and are not to be construed as official or reflecting the views of the Department of the Navy, Department of Defense, of the United States Government. This research has been conducted in compliance with all applicable Federal Regulations governing the Protection of Human Subjects in Research. This Technical Report was approved for publication on 12 July 2004, and designated as NSMRL Technical Report TR #1235.

ABSTRACT

It is increasingly being recognized that understanding expert knowledge structures associated with critical decision processes may facilitate Naval personnel performance. Towards this end, system developers and training researchers attempt to identify critical components of expert operator assessment and knowledge. Differing domains of practice rely to varying degrees on perceptual and conceptual knowledge. Perceptual knowledge is relied upon for recognizing critical cues in the environment whereas conceptual knowledge is used to interpret the meaning and importance of these cues. Via analyses of submariner knowledge for concepts related to responsibilities for the Officer of the Deck (OOD) task, this study examined how training may alter knowledge representation and priority of conceptual importance and how overlap in mental models may be due to amount of experience.

Eighty-three Naval Officers performed a card sorting and ranking task to indicate similarity and relative importance among 20 categories of information available on submarines in different operational environments. These submarine concepts consisted of types of information the submarine OOD would encounter while on watch, with the exception of tactics information. Participants were instructed to sort the cards into piles according to similarity and were not constrained by the number of piles they could create. Following the sorting task participants ranked the cards according to relative importance for four scenarios. They were instructed to create a single pile of cards ordered from the most important piece of submarine information to the least important. Data were collected from Submarine Officer Basic Course (SOBC) students pre and post course, Submarine Officer Advanced Course (SOAC) students, and Post Department Head submariners (PostDH).

Correlations between and among participant groups (SOBCpre, SOBCpst, SOAC, PostDH) revealed differences in cognitive organization of the submarine OOD concepts. Within group comparisons showed that the degree of mental model similarity was significantly greater for more experienced participants. When considering across group comparisons, analyses showed that the degree of across group mental model similarity was greatest for SOAC and SOBCpst. Moreover, SOAC students were in higher agreement with the expert composite model generated from Post DH submariners, and concept rankings varied as a function of experience.

In support of shared mental model theory and consistent with other studies of knowledge organization and the mental models of submariners, this investigation found that more experienced personnel view conceptual linkages more similarly and showed higher agreement with an expert model (Fiore, Fowlkes, Martin-Milham, & Oser, 2000). Conversely, the least experienced personnel see conceptual linkages less similarly, but, following training, these participants were found to view the conceptual linkages more similarly to the experienced personnel. From the standpoint of understanding the importance of particular concepts, significant differences between experienced and novice personnel were identified prior to, and following, training. These data highlight how participants vary in their understanding of the importance of these concepts.

INTRODUCTION

It is increasingly being recognized that understanding expert knowledge structures associated with critical decision processes may facilitate Naval personnel performance (e.g., Gray & Kirschenbaum, 2000; Kirschenbaum, 2001). Towards this end, system developers and training researchers attempt to identify critical components of expert operator assessment and decision processes. From the standpoint of system development, such findings may aid in the identification of important parameters to be included in relevant operational environments (e.g., Schvaneveldt, Beringer, & Lamonica, 2001). From the standpoint of training and performance, targets for learning may be identified (e.g., Fiore, Fowlkes, Martin-Milham, & Oser, 2000). As such, an understanding of the knowledge structures associated with expert decision making is critical to the development of, not only cognitively valid systems, but also efficient training programs.

Performance in many of today's complex tasks (e.g., aviation, nuclear power plants) requires that operators have the ability to, not only rapidly recognize cues in the environment, but also to interpret the meaning and importance of these cues. This former ability is described as a process involving perceptual knowledge, defined here as the veridical and largely unverbalizable representation that develops via multiple exposures to environmental stimuli. The latter ability is described as a process involving conceptual knowledge, defined as a relatively verbalizable component of knowledge which is developed through the integration and structuring of information into meaningful representations (e.g., Lesgold, Rubinson, Feltovich, Glaser, Klopfer, & Wang, 1988; Melcher & Schooler, in press). Previous research has investigated the nature of expert cognitive processes involved in pilot instrument scans within this distinction of perceptual and conceptual knowledge (Fiore, Jentsch, Oser, & Cannon-Bowers, 2000), suggesting that such tasks rely on knowledge types relevant to expert cognitive processes in a variety of domains. Understanding how this knowledge is represented, as well as the processes with which decisions are made, is critical to cognitive engineering and decision making research. For example, such an understanding may facilitate the development of accelerated training programs or improved system design. Lesgold et al. (1988) noted that task novices initially develop perceptual expertise more rapidly than conceptual expertise, but, with experience, the conceptual expertise gains strength.

For the following reasons this investigation focused on conceptual knowledge given its importance in the submariner environment. First, the environment in which a submarine's crew operates differs from the normal environment in significant ways. The submarine environment is a fluid-filled medium, little or no direct visual information is provided, and much of the acoustic information is made available only indirectly and that too is in visual form. As a consequence, mental representations of the submariner's world can be greatly impacted. Second, through technological advances, increasing amounts of information are available to the submarine watchstander, especially the Officer of the Deck (OOD). The OOD controls the boat and executes his mission by making sense of the substantial amount of information presented by external sensors and internal processing. The OOD's task essentially is ship's safety and navigation. The OOD is strategically located at the control center, and receives a variety of diverse information as inputs, making operational decisions based on his understanding. The OOD uses this information to build his mental model, which is important for developing and maintaining situational awareness. Too much or irrelevant information given to the OOD can degrade performance of the man-machine system rather than enhance it. The amount of information available greatly exceeds the capacity of human working memory, so they manage this information load by cognitively organizing it in such a way that needed information can be retrieved from memory as accurately and quickly as possible. The current research describes and models the organization of submarine information used by qualified OODs. Additionally, the development of these cognitive models from novices to experts is explored.

A variety of quantitative and qualitative methods can be used to measure knowledge structures, each possessing unique advantages and disadvantages. Fiore, Fowlkes, Martin-Milham, and Oser (2000) found a degree of convergence in knowledge structure assessment using similarity ratings (e.g., Schvaneveldt, 1990) and card sorting techniques. Specifically, card sorting and similarity ratings were used to assess the manner in which experts view conceptual relations associated with situation awareness. This study showed that knowledge structures measured with card sorting were significantly related to knowledge structures elicited using more time-consuming methods such as Pathfinder similarity ratings. Further, although card sorts are a somewhat limited method because trainees are forced to group together items rather rigidly, previous research does document a relation between task performance and accurate mental model development measured via card sorts. For example, research with card sorting has documented how training systems that enable learners to build an appropriate mental model of the relations between concepts can encourage the acquisition of knowledge structures more similar to an expert model (e.g., Fiore, Cuevas, & Oser, 2003) and also how cognitively diagnostic assessment for complex task training can proceed (Cuevas, Fiore, & Oser, 2002; Fiore, Cuevas, Scielzo, & Salas, 2002). In short, card sorting was chosen because it has been shown to be an effective tool in identifying the level of organization of core concepts as well as being a reliable indicator of how novices evaluate concepts (Fiore et al., 2002; 2003), and experts view conceptual relations (Fiore, Jentsch, Oser, & Cannon-Bowers, 2000).

OBJECTIVES

Two approaches were used to converge on an understanding of how knowledge related to complex tasks may change with experience. This investigation examined how training may alter knowledge representation, and how overlap in mental models may be due to amount of experience. Similar research has assessed the nature and sharedness of mental models for submariners. For example, Smith-Jentsch, Campbell, Milanovich, & Reynolds (2001) looked at how experience influenced mental models of teamwork and found greater agreement based upon either rank or years in service. Additionally, when compared to an expert model, those with a higher rank showed greater agreement. The current research expands upon that work to examine how mental models associated with the OOD task may show similar patterns and further investigate how information priority may change due to experience. Priority rankings data for task related concepts may elucidate differences in conceptual knowledge across groups varying in experience. For example, in a study looking at phases of flight, Schvaneveldt, Beringer, & Lamonica (2001) found that this technique was able to highlight differences in perceptions of importance dependent upon the level of expertise of the pilots.

Based upon shared mental model theory (e.g., Cannon-Bowers, Salas, & Converse, 1993; Fiore, Salas, & Cannon-Bowers, 2001), it was hypothesized: (1) that experienced participants would show greater similarity within their groups and to an expert model; (2) following training, novice participants would show greater agreement in mental models for the critical concepts, and show greater agreement with the experienced participants. The present research additionally examined the degree to which these participants' mental models were similar to an expert model (i.e., a composite model based upon the input of a group of expert participants). Additionally, rankings of importance for these critical concepts were expected to show how novice and less experienced personnel may misunderstand priorities associated with decision-making criteria when compared to experts. Thus, the overall goal was to use differing knowledge elicitation techniques in order to develop an understanding of how it is that experts and novices both classify the concepts associated with complex decision making tasks and understand the importance of these concepts (e.g., Fiore, Fowlkes, Martin-Milham, & Oser, 2000).

METHODS

Participants

Participants were drawn from the submarine community to represent novice, experienced, and expert groups. Novice participants (N = 39) were students in their first week of Submarine Officer Basic Class (SOBCpre) and last week of class (SOBCpst) with no OOD experience. The SOBCpre and SOBCpst groups consisted of the same subjects. The SOBCpst group was not OOD-qualified, but they had all the relevant lectures and trainer experience. Experienced participants (N = 40) were qualified OODs in Submarine Officer Advanced Class (SOAC). As shown in Table 1, Years in Service for participants in the SOBC group (M = 5.12 years) was significantly lower than that of participants in the SOAC group (M = 10.58 years), $F(1, 89) = 34.76$, $p < .001$. Years in Present Rank for participants in the SOBC group (M = 1.6 years) was significantly lower than that of participants in the SOAC group (M = 3.3 years), $F(1, 88) = 62.66$, $p < .001$. Years Sea Duty for participants in the SOBC group (M = 1.1 years) was significantly lower than that of participants in the SOAC group (M = 3.8 years), $F(1, 89) = 35.92$, $p < .001$. Data from a small group of experts (N = 4) were also collected in order to develop a composite model for comparison to less experienced participants. The expert participants were all Lieutenant Commanders (O4) and overall, had an average length of 8.9 years in that rank. The mean number of years in service was 20.4, with an average of 6.5 years submarine sea duty. All of the expert participants had served as department heads on submarines and were currently filling a Post-Department Head shore tour billet. Table 2 provides information on the ranks of the different subject groups.

Table 1. Subjects' Demographic Information

Characteristic		N	Mean	SD
Age				
	SOBC	39	25.2	2.4
	SOAC	40	31.2	2.4
	Post DH	4	40.5	0.6
Years of Service				
	SOBC	39	5.1	3.6
	SOAC	40	10.6	3.5
	Post DH	4	20.4	1.9
Years of Sea Duty				
	SOBC	39	1.1	1.3
	SOAC	40	3.8	1.2
	Post DH	4	6.5	0.6

Table 2. Rank Distribution of Subjects

	Rank				
	O1	O2	O3	O4	O5
Group					
SOBC	37	2	0	0	0
SOAC	0	0	39	1	0
Post DH	0	0	0	4	0

Materials

Various types of information from current and proposed submarine systems were classified into 20 categories. These 20 categories are listed in Appendix A. Descriptions of these categories comprised the 20 stimuli for the tasks to be performed by the subjects. Each of the stimuli was typed on a separate 3" X 5" card and numbered on the reverse side to create the stimulus deck. Some information available to the OOD (e.g., torpedo load out, weapons safeties, countermeasures status, intelligence on contacts in the area) was not included in this investigation because it was more relevant to target prosecution than situational awareness. Several subjects did request such information, which indicates its importance for the OOD, but it was considered outside the scope of the present research.

Design

This experiment manipulated experience level as a between participant factor. For the concept rankings measure, operational scenario was manipulated via factorial combination of presence/absence of enemy and shallow/deep water.

Procedure

All subjects were given a brief overview of the procedure when consent forms were administered, and the research was conducted in compliance with all applicable federal regulations governing the protection of human subjects in research. Prior to the study, participants completed a background questionnaire used to assess their level of experience shown in Appendix B. Next, participants judged the similarity between different categories of information available as OOD. This judgment of similarity is a reflection of the conceptual organization operators employ. Specifically, subjects participated in an unconstrained sorting task. The officers received a set of 20 index cards with a short description of submarine information printed on each, and they arranged these cards into groups according to similarity. The definition of similarity was left up to the subject. Cards which described similar categories were placed in the same group, and any card which described a unique category was placed by itself. The officers could create as many or as few groups as they felt appropriate.

After the sorting task, the officers were asked to rank the information items according to importance. They ranked the items four times, once for each of four different operational scenarios, described in Appendix C. The factors that varied over the four scenarios were the type of contact (neutral vs. hostile) and the type of environment (deep water vs. shallow water). The first scenario was an AntiSubmarine Warfare (ASW) patrol in a shallow water environment (i.e., littoral sea; "brown water") with a hostile contact. The second scenario was the same as the first, except the contact was neutral. The third scenario was an ASW patrol in a deep water environment (i.e., pelagic ocean; "blue water") with a hostile contact. Finally, the fourth scenario was the same as the third except the contact was neutral. These four scenarios differ greatly in the quality and quantity of information available to the OOD. After each of the tasks, subjects recorded their responses on answer sheets according to the code number on the back of each stimulus card.

RESULTS

For the card sort data, in order to assess the relation among concept pairs, each possible concept pair (N = 210) was coded with a 0 if the participant did not group them in the same category, or a 1 if they were grouped in the same category. For the concept rankings data, mean concept importance was calculated for each concept across participant groups and scenarios.

The results for the three primary groups (SOBCpre, SOBCpst, SOAC) are presented, and where appropriate, the expert composite model generated from the PostDH subjects is included.

Mental Model Similarity for Card Sort Data - Overall Correlations

These data determine the degree to which participants may differ in their mental models of critical OOD concepts. Using the concept pair coding scheme described above, correlations with all possible participant pairings were computed. These cross-correlations were run across and within the three participant groups (SOAC, SOBCpre, SOBCpst). Based upon this matrix, the data had six conceptual groups: (1) SOAC correlated with SOAC; (2) SOAC correlated with SOBCpst; (3) SOAC correlated with SOBCpre; (4) SOBCpre correlated with SOBCpst; (5) SOBCpst correlated with SOBCpst; and, (6) SOBCpre correlated with SOBCpre. These data were subjected to a Univariate ANOVA and resulted in a significant main effect for group type, $F(5, 8250) = 20.95$, $p < .001$. For ease of explication these data are presented as mean *within* group correlations and mean *across* group correlations. Specifically, the *within* group correlations correspond to "SOAC correlated with SOAC," "SOBCpst correlated with SOBCpst," and "SOBCpre correlated with SOBCpre". The *across* group correlations correspond to "SOAC correlated with SOBCpst," "SOAC correlated with SOBCpre," and "SOBCpre correlated with SOBCpst" (Refer to Figure 1). Unless otherwise specified, the reported post-hoc analyses are all significant at the $p < .05$ level.

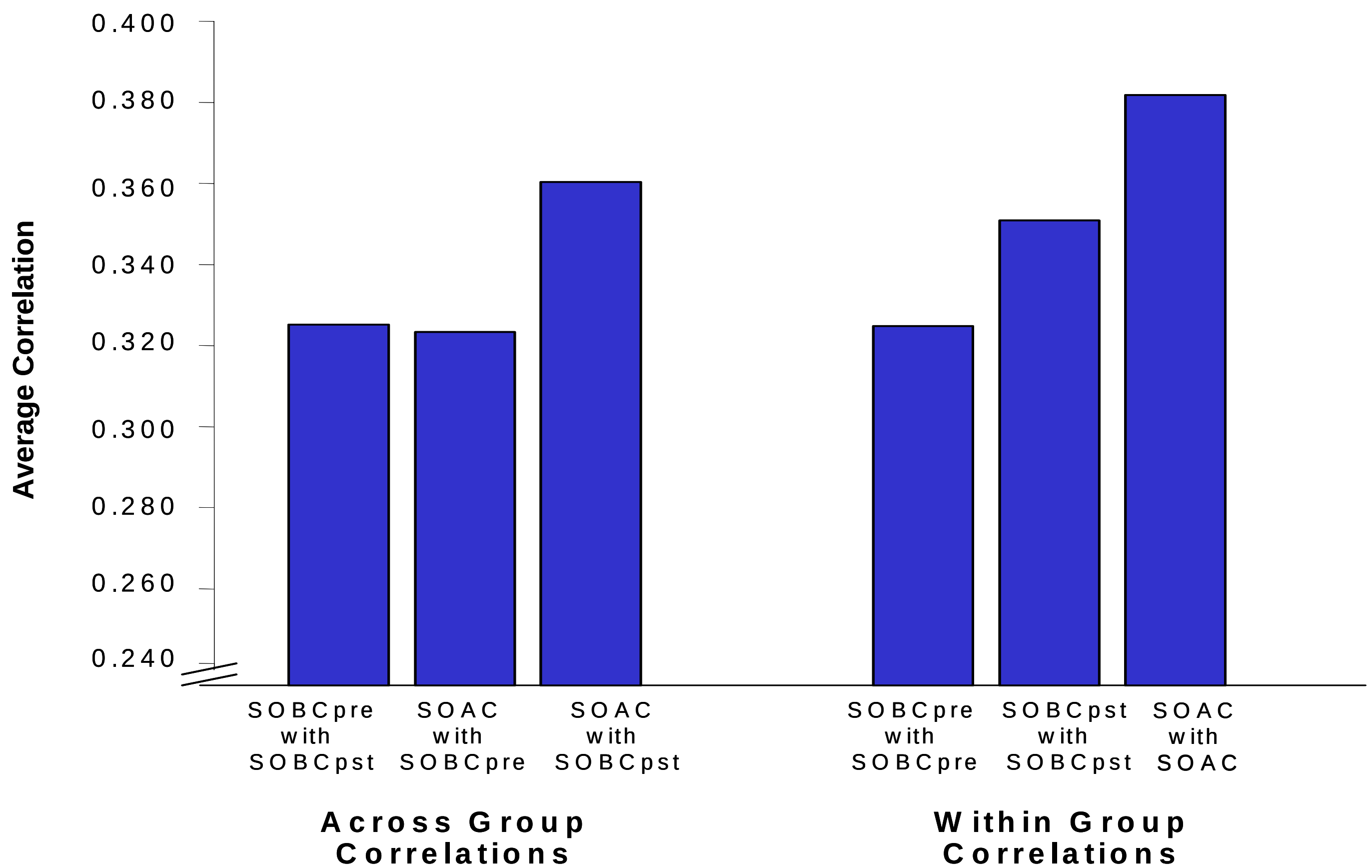

Figure 1. Mean correlations across participant pairings resulting from card sort data.

When considering the *within* group comparisons, post-hoc analyses showed that the degree of mental model similarity was significantly greater for the more experienced (SOAC) participants (M = .39). The degree of mental model similarity was significantly lower for the least experienced (SOBCpre) participants (M = .33) with mental model similarity for SOBCpst in between, and significantly different from, the other groups (M = .35). When considering the *across* group comparisons, post-hoc analyses showed that the degree of across group mental model similarity was greatest for SOAC and SOBCpst (M = .36). Correlations between SOBCpre and SOBCpst (M = .33) and between SOAC and SOBCpre (M = .33) were both significantly lower than the correlation between SOAC and SOBCpst.

Years of Experience and Group Correlations

Next, the cross-correlations based upon the absolute difference in Years of Experience for the participants in each pair were parsed. This involved computing a difference score in the "Years of Experience" for all participant cross-correlations. For example, if one participant had 11 years of experience, and the other had 2 years of experience, their difference score was 9 years for the correlation on which they were compared. Based upon this difference score two groups of cross-participant correlations were created for more detailed analysis. The first group (low_diff) consisted of correlations based upon participant pairs with a difference score less than 2 years. The second group (high_diff) consisted of correlations based upon participant pairs with a difference score greater than 8 years. Groups were then compared in order to determine the degree to which years of experience may alter the similarity of participants' view of the critical conceptual relations. For illustrative purposes, Figure 2 shows the mean correlations.

When considering the *within* group comparisons, for the card sort data from novice participants *prior* to training (i.e., SOBCpre), the mean correlation for the low_diff group (M = .34) was numerically greater than the mean correlation for the high_diff group (M = .31). This difference revealed a trend toward significance, $F(1, 524) = 2.73$, $p < .10$. For the card sort data from novice participants *following* training (i.e., SOBCpst), the mean correlation for the low_diff group (M = .38) was significantly greater than the mean correlation for the high_diff group (M = .33), $F(1, 524) = 10.20$, $p < .01$. When considering the card sort data from experienced participants (i.e., SOAC), the mean correlation for the low_diff group (M = .41) was not significantly different ($F < 1$) from the mean correlation for the high_diff group (M = .39).

When considering the *across* group comparisons comparing the card sort data from novice participants *prior* to and *following* training (i.e., SOBCpre and SOBCpst), the mean correlation for the low_diff group (M = .35) was significantly greater than the mean correlation for the high_diff group (M = .31), $F(1, 1099) = 17.89$, $p < .001$. When considering the *across* group comparisons comparing the novice participants *prior* to training with experienced participants (i.e., SOBCpre and SOAC), the mean correlation for the low_diff group (M = .31) was significantly lower than the mean correlation for the high_diff group (M = .34), $F(1, 904) = 4.36$, $p < .05$. Last, when considering the *across* group comparisons comparing the novice participants *following* training with experienced participants (i.e., SOBCpst and SOAC), the mean correlation for the low_diff group (M = .36) was not significantly different from the mean correlation for the high_diff group (M = .37), ($F < 1$).

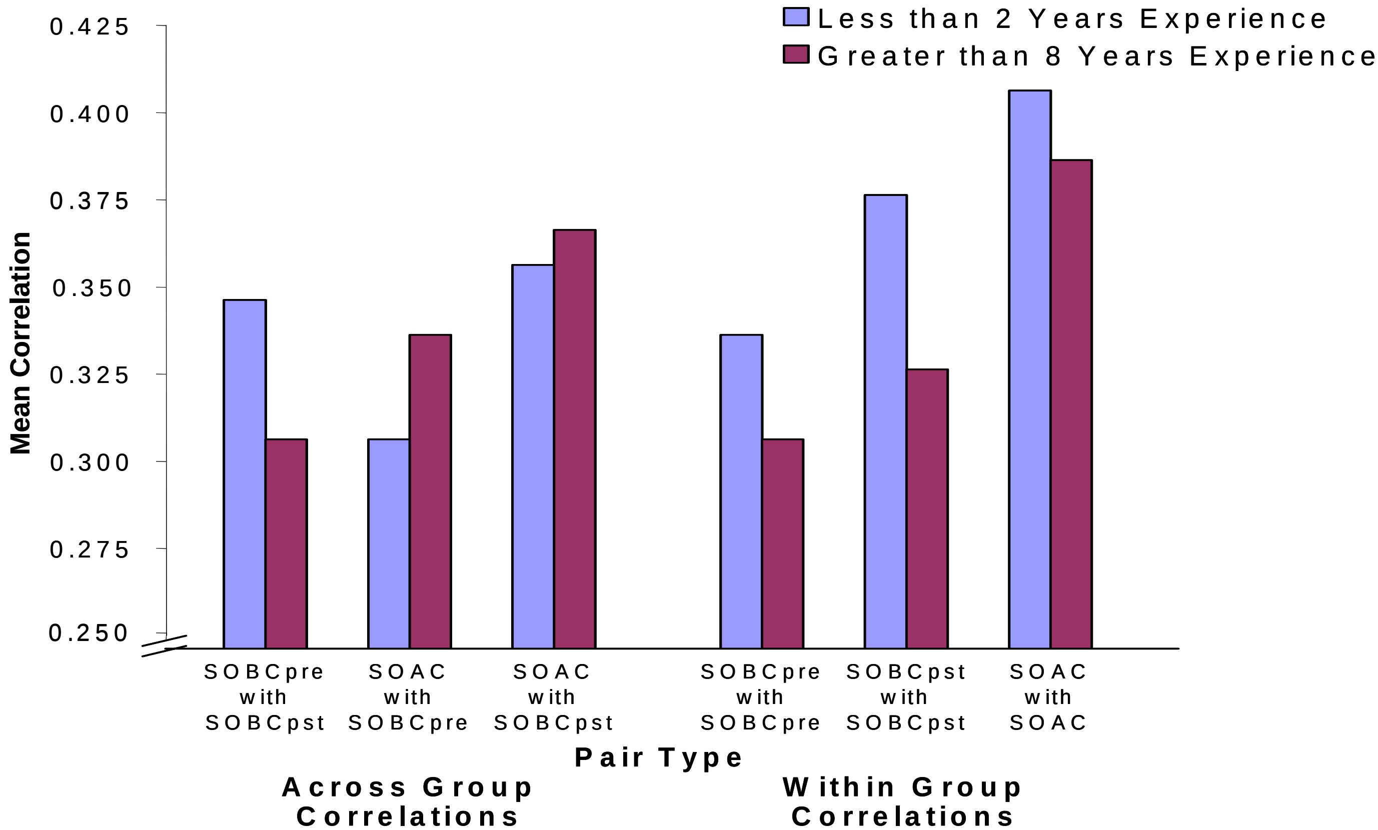

Figure 2. Mean card sort correlations for all groups based upon years experience differential.

Mental Model Similarity for Card Sort Data - Similarity to Expert Composite Model

Additionally, the degree to which these participant groups generated mental models similar to a composite expert model based on the PostDH subjects was examined. One question of the present research was whether training and/or experience influenced structural similarity to an expert model, and it was hypothesized that the differing groups would show differing levels of similarity to the expert model. For this analysis mean correlations with the expert composite model for each participant group were computed. An ANOVA revealed a main effect of group F (2, 126) = 19.76, $p < .001$. Post-hoc analyses showed that the SOAC participants (M = .43) were significantly higher in agreement to the expert model than were the SOBCpst participants (M = .35), who were, in turn, significantly higher than the SOBCpre participants (M = .28).

Concept Rankings of Importance Compared to Expert Composite Model

In this section the degree to which submariners view *concept importance* differently was analyzed. This analysis has both theoretical and practical value. These data are theoretically important because, from the mental model standpoint, it distinguishes experts/novices on the basis of *critical misconceptions* in item importance. These data are practically important because these misconceptions can be considered as targets for training. For example, this allows one to identify over- and under-statement of importance for trainees at different levels. This, in turn, suggests what concepts need augmentation in the training (i.e., where misconceptions in concept importance lie before and after training).

Next, the results pertaining to the degree to which less experienced submariners view concept importance differently compared to the expert composite model is discussed. Cluster analysis of the card sort data for the expert composite group, PostDH subjects, was used to identify clusters (reported in Shobe & Carr, 2004). Refer to Shobe & Carr (2004) for a discussion on the differences between clusters for the different participant groups. The clusters identified for the expert composite group are shown in Table 3. These clusters served as an organizing framework with which to analyze and interpret the differences in importance ratings and more specifically target problematic concepts within the overall knowledge structure. For the participants' priority ratings, there were no significant differences between shallow versus deep water scenarios; therefore only effects based upon experience level and presence/absence of an enemy contact will be presented. Only the overall effects for the rankings data and the comparisons to the expert group are reported. For reference, the rankings for the expert group are shown in Appendix D. For illustrative purposes, these concepts are graphed according to a difference score calculated using the mean expert score. A negative score means participants within a given group, on average, viewed this concept as less important than the expert composite group. For each cluster analyzed, the relevant statistics, tables, and figures for the data are presented.

Table 3. Cluster analysis results for Post DH subjects.

Group	Item
Own Ship Parameters/Contact Management	Own ship data
	Electronic Support Measures (ESM) contact data
	Visual contact data
	Geosit/ops summary
	Trial own ship
	Non-target fire control solution
	Target fire control solution
Ship System Status	Propulsion Plant Lineup
	Ship's atmosphere
	Potable water status
	Sanitary tank status
Equipment Lineup/Search Data	Counterdetectability data
	Sonar search plan
	Active sonar lineup
	Sonar lineup
	Ocean environment and navigation data
Sonar Tactical Displays	Performance Monitoring/Fault Location (PMFL) data
	Sonar tracker/cursor audio
	Sonar detection displays
	Sonar class displays

Own Ship Parameters and Contact Management Cluster

Table 4 shows the concepts for the "Own Ship Parameters and Contact Management" cluster identified for the expert group. The mean concept importance ratings for the four groups (SOBCpre, SOBCpst, SOAC, PostDH) were subjected to a Multivariate ANOVA. Group type was the independent factor and the seven concepts identified in Table 4 were the dependent variables. There was a significant multivariate main effect for group type, $F(21, 1560) = 6.51$, $p < .001$. For ease of explication, Appendix E presents the between subjects effects for this analysis. Similarly, Figure 3 illustrates the pattern of differences for the effect of group type on mean concept rankings for the Own Ship Parameters and Contact Management cluster. Significant differences between the expert group and the participant groups are noted in the footnotes in Appendix E.

Table 4. Concept names and explanations for the Own Ship Parameters and Contact Management cluster.

Card	Concept	Description
1	*ESM contact data*	Bearing and classification of radar and communications systems data provided by the Electronic Support Measures system
2	*Own ship data*	Own ship's course, speed, depth, etc.
8	*Visual contact data (from photonics mast)*	Visual information on surface contacts including night vision, infrared, video, laser ranging, etc.
14	*Geosit/ops summary*	Computer generated geographical picture of contacts and own ship, in either true or relative bearing orientation, with classification information where possible
15	*Trial own ship*	Closest Point of Approach (CPA) solutions, trial maneuvers, etc., i.e., data which aid in assessment of the present and future tactical situation
16	*Non-target fire control solution*	Rapid passive localization by wide aperture array (WAA), KAST ranging, multipath ranging, D/E ranging, hyperbolic ranging; Bearing, range, course, speed, depth if submerged contact, for secondary contacts
19	*Target fire control solution*	Rapid passive localization by wide aperture array (WAA), KAST ranging, multipath ranging, D/E ranging, hyperbolic ranging; Bearing, range, course, speed, depth if submerged contact, for target of interest

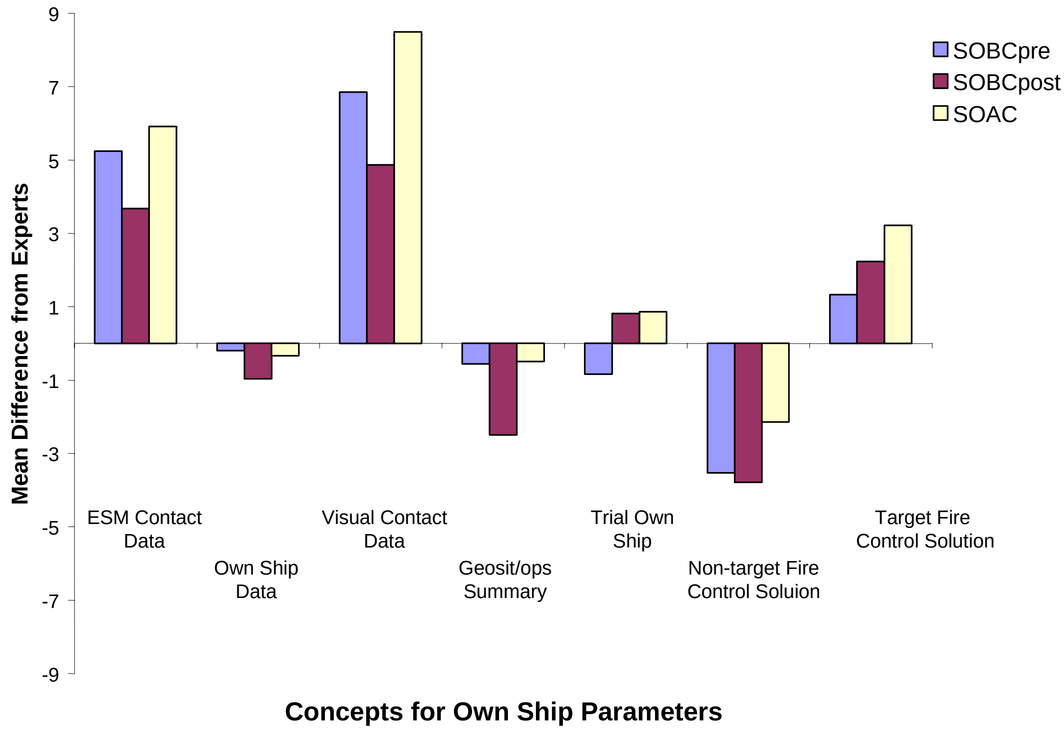

Figure 3. Ranking difference scores for Own Ship Parameters and Contact Management Cluster.

Ship System Status Cluster

Table 5 lists and defines the concepts making up the "Ship System Status" cluster. The mean concept importance ratings for the four groups (SOAC, SOBCpre, SOBCpst, PostDH) was subjected to a Multivariate ANOVA. Group type was the independent factor and the four concepts identified in Table 5 were the dependent variables. There was a significant multivariate main effect for group type, $F(12, 1569) = 5.14$, $p < .001$. For ease of explication, Appendix F presents the between subjects effects for this analysis. Similarly, Figure 4 illustrates the pattern of differences for the effect of group type on mean concept rankings for the Sonar Tactical Displays cluster. Significant differences between the expert group and the participant groups are noted in the footnotes for Appendix F.

Table 5. Concept names and explanations for the Ship System Status cluster.

Card	Concept	Description
6	*Propulsion Plant Lineup*	Operating condition of the reactor and propulsion equipment including reactor coolant pump speed (fast, slow, reduced frequency operations (RFO); electric plant lineup (full power, half power, other); any limits on operations due to casualties or maintenance in the engineering spaces
9	*Potable water status*	Amount of water in potable water tanks and tank on service
11	*Ship's atmosphere*	Status of atmosphere inside the submarine (oxygen percentage, CO_2 concentration percentage, CO/H_2 concentrations); status of oxygen bleed from O_2 banks; status of oxygen generator or O_2 candle furnace; status of CO_2 scrubbers and CO/H_2 burner
13	*Sanitary tank status*	Tank levels in ship's sanitary tanks and status of pumping or blowing tanks

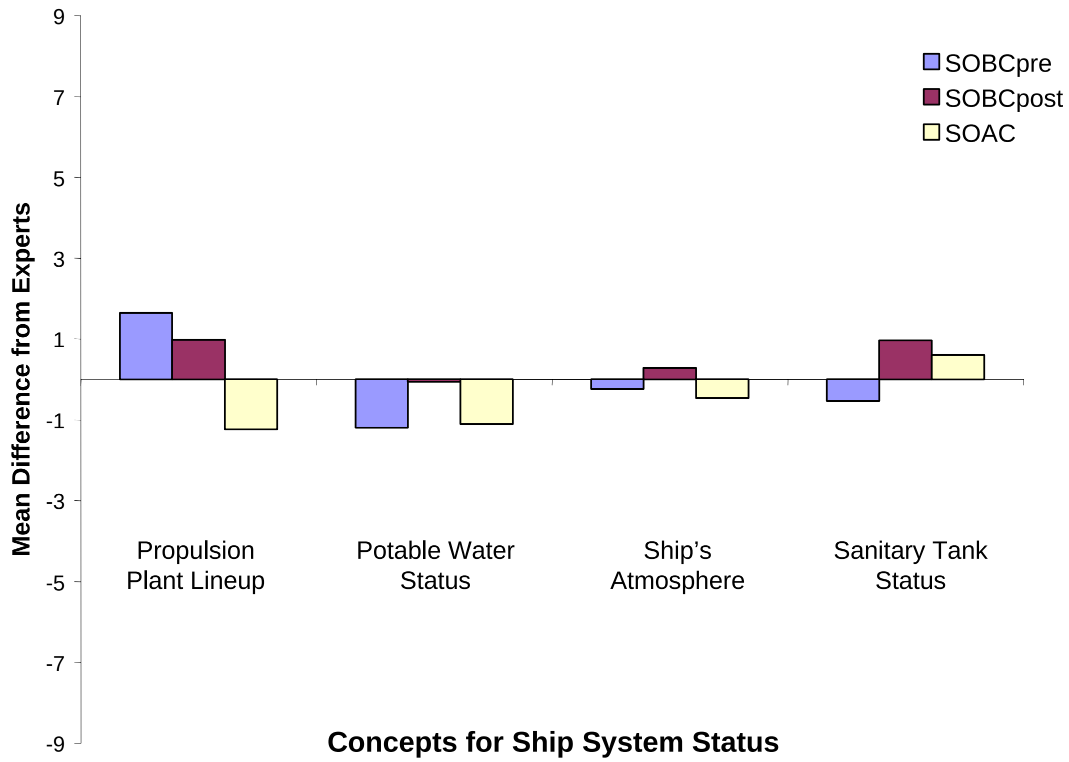

Figure 4. Ranking difference scores for Ship System Status Cluster.

Equipment Lineup/Search Data Cluster

Table 6 lists and defines the concepts making up the "Equipment Lineup/Search Data" cluster. The mean concept importance ratings for the four groups (SOAC, SOBCpre, SOBCpst, PostDH) were subjected to a Multivariate ANOVA. Group type was the independent factor and the five concepts identified in Table 6 were the dependent variables. There was a significant multivariate main effect for group type, $F(15, 1563) = 11.76$, $p < .001$. For ease of explication, Appendix G presents the between subjects effects for this analysis. Similarly, Figure 5 illustrates the pattern of differences for the effect of group type on mean concept rankings for the Sonar Tactical Displays cluster. Significant differences between the Expert group and the participant groups are noted in the footnotes for Appendix G.

Table 6. Concept names and explanations for the Equipment Lineup/Search Data cluster.

Card	**Concept**	**Description**
4	*Ocean environment and navigation data*	Sea state; bottom depth; type, and features; background noise; sound velocity profile; propagation loss, i.e., computer generated data used to position own ship to maximize sonar detection range (L_e)
5	*Counter-detectability data*	Own ship electromagnetic signature, radiated noise, surface visibility/wake, contaminants, etc.
7	*Sonar search plan*	Physical lineup of sonar system, including operator displays and processing used; search track to be followed by ship to locate target of interest; depth to search at based on ocean bathymetric data
10	*Active sonar lineup*	Power, pulse type, range gate, etc., i.e., parameters indicating active sonar transmission status
18	*Sonar lineup*	Narrow band and broadband detection system lineup, filter and alarm settings, other operator set parameters

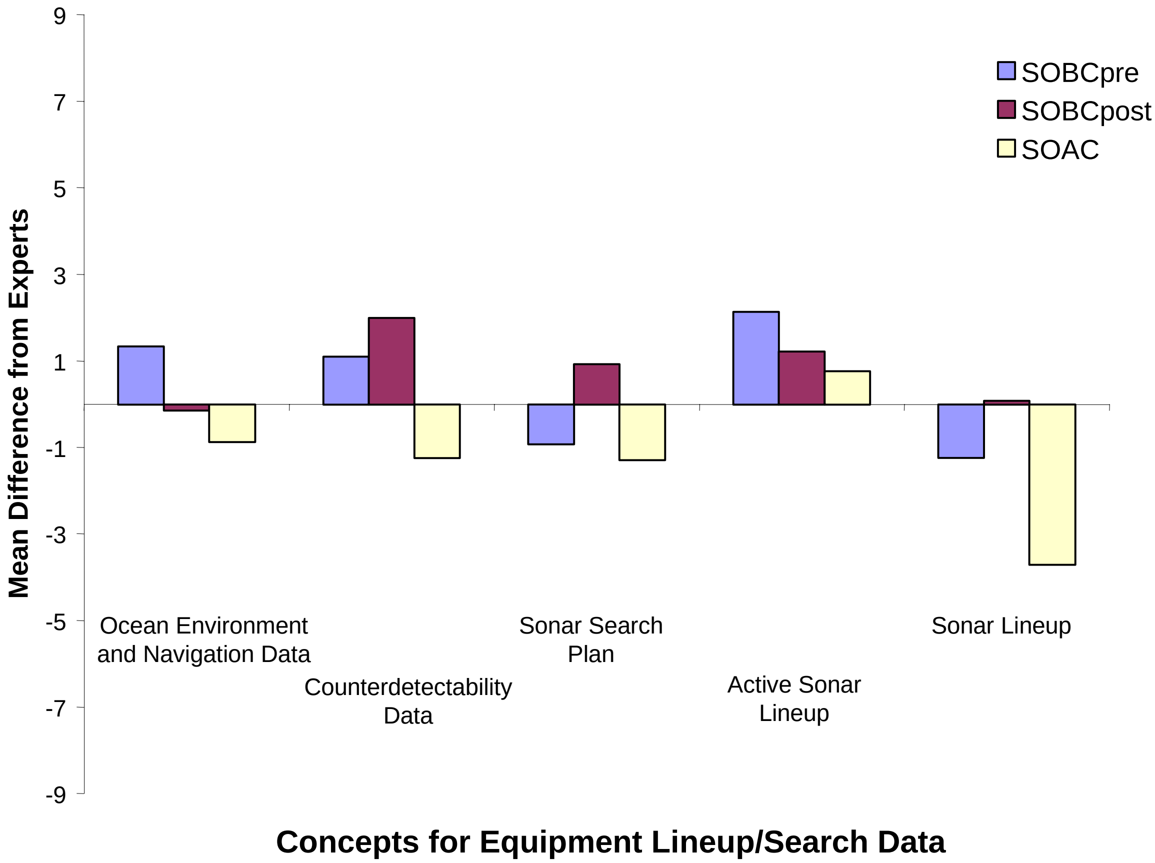

Figure 5. Ranking difference scores for Equipment Lineup/Search Data Cluster.

Sonar Tactical Displays Cluster

Table 7 lists and defines the concepts making up the "Sonar Tactical Displays" cluster for the expert group. The mean concept importance ratings for the four groups (SOAC, SOBCpre, SOBCpst, PostDH) were subjected to a Multivariate ANOVA. Group type was the independent factor and the four concepts identified in Table 7 were the dependent variables. There was a significant multivariate main effect for group type, $F(12, 1569) = 12.06$, $p < .001$. For ease of explication, Appendix H presents the between subjects effects for this analysis. Similarly, Figure 6 illustrates the pattern of differences for the effect of group type on mean concept rankings for the Sonar Tactical Displays cluster. Significant differences between the expert group and the participant groups are noted in the footnotes of Appendix H.

Table 7. Concept names and explanations for the Sonar Tactical Displays cluster.

Card	Concept	Description
3	*PMFL data*	Data on fault location and performance monitoring of various sonar components, i.e., data required to maintain electrical information systems
12	*Sonar tracker/cursor audio*	Auditory presentation of minimally processed sonar signals as picked up by the various arrays
17	*Sonar detection displays*	Visual displays of sonar detections as presented to sonar operators
20	*Sonar class displays*	Sonar signal interpretation aids such as signature assemblies, lofargrams, etc., i.e., data used to aid in the classification of signals

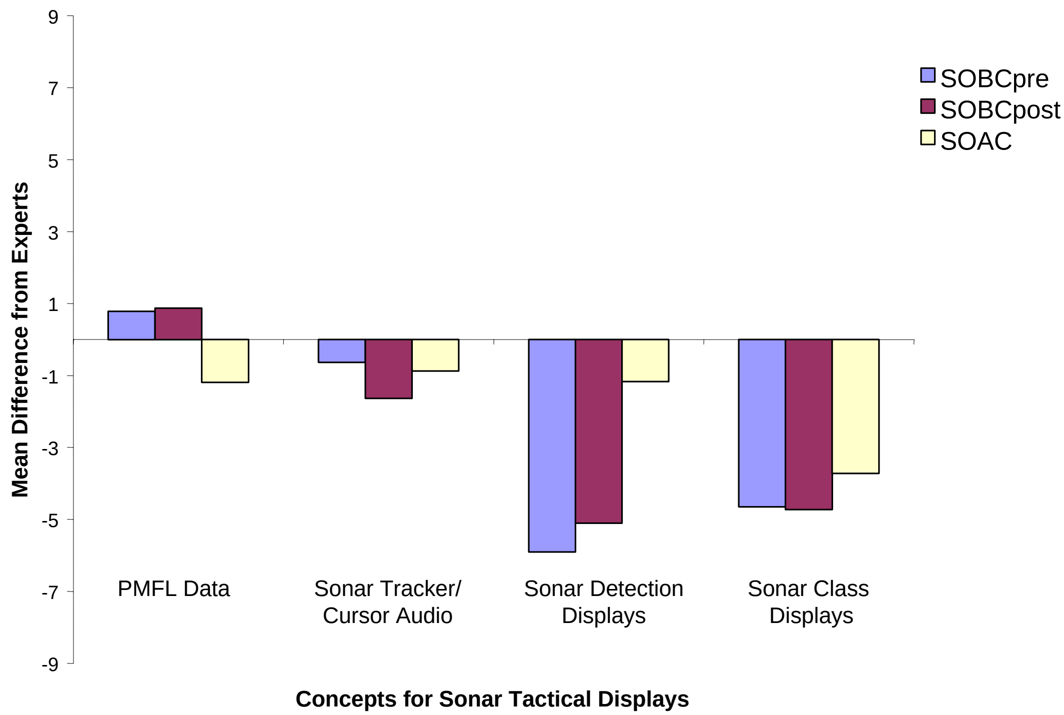

Figure 6. Ranking difference scores for Sonar Tactical Displays Cluster.

The previous analysis compared the ranking scores for the various subject groups to the expert composite model. This analysis was done for the concepts within each of the four clusters identified in the PostDH cluster analysis. For the Own Ship Parameters and Contact Management cluster, the less experienced personnel consistently ranked ESM contact data, visual contact data, and target fire control solution as more important than the experts, while own ship data, geosit/ops summary, and nontarget fire control solution were ranked as less important than experts. Visual contact data demonstrated the largest discrepancy between groups. For the ship system status cluster, SOAC subjects consistently ranked the items as less important than experts (except for sanitary tank status), with minor differences for the SOBCpre and SOBCpst subjects. The largest difference in the equipment lineup/search data cluster were the rankings for sonar lineup which SOAC subjects ranked as less important than experts. The other differences between groups and items were minimal. Finally, for the sonar tactical displays cluster, the less experienced personnel ranked sonar detection displays and sonar class displays as less important than experts. These results pinpoint concept areas that should be the focus of training for the less experienced submarine officers.

DISCUSSION

This report, in conjunction with Shobe & Carr (2004), demonstrates significant differences in the way submarine officers conceptually organize and prioritize concepts available to the Officer of the Deck. Even though each subject group organized the concepts along two dimensions (Shobe & Carr, 2004), the organization within these dimensions varied as a result of experience. Moreover, as the personnel gained more experience, they required few clusters to classify the information items. Within these clusters, differences in concept importance were identified compared to an expert composite model.

In support of shared mental model theory and consistent with other studies of knowledge organization and the mental models of submariners (e.g., Smith-Jentsch et al., 2001), this investigation found that more experienced personnel view conceptual linkages more similarly and showed higher agreement with an expert model (Fiore et al., 2000). Conversely, the least experienced personnel see conceptual linkages less similarly, but, following training, these participants were found to view the conceptual linkages more similarly to the experienced personnel. From the standpoint of understanding the importance of particular concepts, significant differences between experienced and novice personnel were identified prior to, and following, training. These data highlight how participants vary in their understanding of the importance of these concepts.

Linking the conceptual groupings with the priorities data can better illuminate knowledge organization and the differing ways that knowledge may be tapped in operational environments (cf. Schvaneveldt et al., 2001). From the standpoint of training, these data suggest that the conceptual grouping garnered from the expert group may aid in conveying important clusters of information as well as how priorities vary within these clusters. These data are theoretically important because, from the mental model standpoint, it distinguishes more and less experienced personnel on the basis of *critical misconceptions* in item importance. These data are practically important because these misconceptions can be considered as targets for training. For example, this allows one to identify over- and under-statement of importance for trainees at different levels. This, in turn, suggests what concepts need augmentation in the training (i.e., where misconceptions in concept importance lie before and after training) and may help with redesign of systems based upon the importance of data.

REFERENCES

Cannon-Bowers, J. A., Salas, E., & Converse, S. A. (1993). Shared mental models in expert team decision making. In N. J. Castellan, Jr. (Ed.), *Current issues in individual and group decision making* (pp. 221-246). Hillsdale, NJ: Lawrence Erlbaum Associates.

Cuevas, H. M., Fiore, S. M., & Oser, R. L. (2002). Scaffolding cognitive and metacognitive processes: Use of diagrams in computer-based training environments. *Instructional Science. 30*, 433-464.

Fiore, S. M., Cuevas, H. M., Scielzo, S., & Salas, E. (2002). Training individuals for distributed teams: Problem solving assessment for distributed mission research. *Computers in Human Behavior, 18*, 125-140.

Fiore, S. M., Cuevas, H. M., & Oser, R. L. (2003). A picture is worth a thousand connections: The facilitative effects of diagrams on task performance and mental model development. *Computers in Human Behavior, 19*, 185-199.

Fiore, S. M., Fowlkes, J., Martin-Milham, L., & Oser, R. L. (2000). Convergence or divergence of expert models: On the utility of knowledge structure assessment in training research. *Proceedings of the 44th Annual Meeting of the Human Factors and Ergonomic Society, 2, 427-430*, Santa Monica, CA: Human Factors and Ergonomics Society.

Fiore, S. M., Jentsch, F., Oser, R., & Cannon-Bowers, J. A. (2000). Perceptual and conceptual processing in expert/novice cue pattern recognition. *International Journal of Cognitive Technology, 5, 17-26.*

Fiore, S. M., Salas, E., & Cannon-Bowers, J. A. (2001). Group dynamics and shared mental model development. In M. London (Ed.), *How people evaluate others in organizations: Person perception and interpersonal judgment in Industrial/Organizational psychology* (pp. 309 – 336). Mahwah, NJ: Lawrence Erlbaum.

Gray, W. D., & Kirschenbaum, S. S. (2000). Analyzing a novel expertise: An unmarked road. In J. M. C. Schraagen, S. F. Chipman, & V. L. Shalin (Eds.), *Cognitive task analysis* (pp. 275-290). Mahwah, NJ: Erlbaum.

Kirschenbaum, S. S. (2001). Analyzing submarine decision making: A question of levels. In E. Salas and G. Klein (Eds.), *Linking expertise and naturalistic decision making* (pp. 189-207). Mahwah, NJ: Lawrence Erlbaum Associates, Inc.

Lesgold, A.M., Rubinson, H., Feltovich, P., Glaser, R., Klopfer, D. & Wang, Y. (1988). Expertise in a complex skill: Diagnosing x-ray pictures. In M.T.H. Chi, R. Glaser & M.J. Farr (Eds.), *The nature of expertise* (pp. 311-342). Hillsdale, NJ: Erlbaum.

Melcher, J. M. & Schooler, J. W. (in press). Perceptual and conceptual training mediate the verbal overshadowing effect in an unfamiliar domain. *Memory & Cogntion*.

Schvaneveldt, R. W. (1990). Pathfinder associative networks: Studies in knowledge organization. Norwood, NJ: Ablex.

Schvaneveldt, R. W., Beringer, D. B., Lamonica, J. A. (2001). Priority and organization of information accessed by pilots in various phases of flight. *International Journal of Aviation Psychology, 11(3)*, 253-280.

Shobe, K., & Carr, W. (2004). *Submarine Information Organization and Prioritization and Submarine Officer of the Deck Experience* (NSMRL Technical Report No. 1234). Groton, CT. Naval Submarine Medical Research Laboratory.

Smith-Jentsch, K. A., Campbell, G. E., Milanovich, D. M., & Reynolds, A. M. (2001). Measuring teamwork mental models to support training needs assessment, development, and evaluation: Two empirical studies. *Journal of Organizational Behavior, 22(SpecIssue)*, 179-194.

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APPENDIX A Information Categories Available to the OOD at CONN

1. ESM contact data	Bearing and classification of radar and communications systems data provided by the Electronic Support Measures system
2. Own ship data	Own ship's course, speed, depth, etc.
3. PMFL data	Data on fault location and performance monitoring of various sonar components, i.e., data required to maintain electrical information systems
4. Ocean environment and navigation data	Sea state; bottom depth; type, and features; background noise; sound velocity profile; propagation loss, i.e., computer generated data used to position own ship to maximize sonar detection range (L_e)
5. Counterdetectability data	Own ship electromagnetic signature, radiated noise, surface visibility/wake, contaminants, etc.
6. Propulsion Plant Lineup	Operating condition of the reactor and propulsion equipment including reactor coolant pump speed (fast, slow, RFO); electric plant lineup (full power, half power, other); any limits on operations due to casualties or maintenance in the engineering spaces
7. Sonar search plan	Physical lineup of sonar system, including operator displays and processing used; search track to be followed by ship to locate target of interest; depth to search at based on ocean bathymetric data
8. Visual contact data (from photonics mast)	Visual information on surface contacts including night vision, infrared, video, laser ranging, etc. (Note: only available at PD)
9. Potable water status	Amount of water in potable water tanks and tank on service
10. Active sonar lineup	Power, pulse type, range gate, etc., i.e., parameters indicating active sonar transmission status
11. Ship's atmosphere	Status of atmosphere inside the submarine (oxygen percentage, CO_2 concentration percentage, CO/H_2 concentrations); status of oxygen bleed from O_2 banks; status of oxygen generator or O_2 candle furnace; status of CO_2 scrubbers and CO/H_2 burner
12. Sonar tracker/cursor audio	Auditory presentation of minimally processed sonar signals as picked up by the various arrays
13. Sanitary tank status	Tank levels in ship's sanitary tanks and status of pumping or blowing tanks
14. Geosit/ops summary	Computer generated geographical picture of all contacts and own ship, in either true or relative bearing orientation, with classification information where possible
15. Trial own ship	CPA solutions, trial maneuvers, etc., i.e., data which aid in assessment of the present and future tactical situation
16. Non-target fire control solution	Rapid passive localization by wide aperture array (WAA), KAST ranging, multipath ranging, D/E ranging, hyperbolic ranging; Bearing, range, course, speed, depth if submerged contact, for secondary contacts
17. Sonar detection displays	Visual displays of sonar detections as presented to sonar operators
18. Sonar lineup	Narrow band and broadband detection system lineup, filter and alarm settings, other operator set parameters
19. Target fire control solution	Rapid passive localization by wide aperture array (WAA), KAST ranging, multipath ranging, D/E ranging, hyperbolic ranging; Bearing, range, course, speed, depth if submerged contact, for target of interest
20. Sonar class displays	Sonar signal interpretation aids such as signature assemblies, lofargrams, etc. i.e., data used to aid in the classification of signals

APPENDIX B Background Survey

Please provide responses to the following to help us evaluate the results of this experiment.

1. Present rank ____

2. Years in rank ____

3. Age ____

4. Years in service ____

5. Years Sea Duty ____

6. Sea Billets ____

   ____

   ____

   ____

   ____

7. Present billet ____

8. Training (e.g., SOBC, SOAC, JO courses, PXO, PCO)
   ____

APPENDIX C Scenarios Used for Prioritization Task

INSTRUCTIONS FOR RANKING TASK 1

We would now like you to reassemble the cards into a single deck. Then, rank the information on the cards according to importance for display at CONN.

For context, the operational environment should be assumed to be a SSN in the following scenario:

Mission: (littoral, enemy contacts)
The world situation is that a war has broken out between Russia and Ukraine over control of the formerly Soviet Navy. Both nations are trying to get the U.S. involved and have been attacking U.S. shipping with submarines and then blaming each other. You are patrolling in the eastern Mediterranean Sea. Your mission is to protect U.S. shipping lanes. Your orders are to search and destroy any enemy submarines in the vicinity of U.S. shipping. There are several surface contacts (i.e., merchants, fishing trawlers), and no subsurface contacts. The broad band range of the day for a subsurface contact is 3-6 Kyd. Intelligence has indicated a Kilo-type Formerly Soviet Submarine is patrolling in the area. There are no friendly submarines in your patrol area. The month is April and the sea state is 2.
OS Course: 120   Speed: 5   Operating Depth: 250-400ft

INSTRUCTIONS FOR RANKING TASK 2

Again, we would like you to reassemble the cards into a single deck. Then, rank the information on the cards according to importance for display at CONN.

For context and unlike Ranking Task 1, the operational environment should be assumed to be a SSN in the following scenario:

Mission: (littoral, no enemy contacts)
The world situation is that it is peacetime and there are no conflicts brewing. You are on a training exercise in the eastern Mediterranean Sea. There are several surface contacts (i.e., merchants, fishing trawlers) and there is a friendly submarine in your patrol area, a Trafalgar class British sub. The broad band range of the day for a subsurface contact is 3-6 Kyd. The month is April and the sea state is 2.
OS Course: 120   Speed: 5   Operating Depth: 250-400ft

INSTRUCTIONS FOR RANKING TASK 3

We would now like you to reassemble the cards into a single deck. Then, rank the information on the cards according to importance for display at CONN.

Unlike the previous scenarios, the operational environment should be assumed to be a SSN in the following scenario:

Mission: (deep water, enemy contacts)
The world situation is that a war has broken out between Russia and Ukraine over control of the formerly Soviet Navy. Both nations are trying to get the U.S. involved and have been attacking U.S. shipping with submarines and then blaming each other. You are underway from the East Coast and are cruising along to the eastern Mediterranean Sea. Once you arrive, your mission is to protect U.S. shipping lanes. Your orders are to search and destroy any enemy submarines in the vicinity of U.S. shipping. While you are underway, in the middle of the Atlantic Ocean, intelligence has indicated a Kilo-type Formerly Soviet Submarine is in the area. The month is April and the sea state is 2.
OS Course: 120 Speed: 20 Operating Depth: 500

INSTRUCTIONS FOR RANKING TASK 4

We would now like you to reassemble the cards into a single deck. Then, rank the information on the cards according to importance for display at CONN.

Unlike the previous scenarios, the operational environment should be assumed to be a SSN in the following scenario:

Mission: (deep water, no enemy contacts)
The world situation is that it is peacetime and there are no conflicts brewing. You are underway in the Atlantic Ocean to a training exercise in the eastern Mediterranean Sea. There are a few commercial surface contacts and there is a friendly submarine in the area, a Trafalgar class British sub. The broad band range of the day for a subsurface contact is 3-6 Kyd. The month is April and the sea state is 2.
OS Course: 120 Speed: 20 Operating Depth: 500

APPENDIX D Ranking Data for Post DH Participants

Rank	Deep/Neutral	Deep/Hostile	Shallow/Neutral	Shallow/Hostile
1	Sonar Detection Displays	Sonar Detection Displays	Sonar Detection Displays	Sonar Detection Displays
2	Target Fire Control Solution	Own Ship Data	Own Ship Data	Own Ship Data
3	Own Ship Data	Geosit/Ops Summary	Geosit/Ops Summary	Geosit/Ops Summary
4	Geosit/Ops Summary	NonTarget Fire Control Solution	NonTarget Fire Control Solution	Sonar Class Displays
5	NonTarget Fire Control Solution	Sonar Class Displays	Target Fire Control Solution	NonTarget Fire Control Solution
6	Sonar Class Displays	Counterdetectability Data	Counterdetectability Data	Ocean Environment
7	Trial Own Ship	Ocean Environment	Trial Own Ship	Trial Own Ship
8	Ocean Environment	Sonar Tracker/Cursor Audio	Sonar Class Displays	Counterdetectability Data
9	Sonar Search Plan	Trial Own Ship	Ocean Environment	Propulsion Plant Lineup
10	Sonar Lineup	Propulsion Plant Lineup	Propulsion Plant Lineup	Sonar Search Plan
11	Counterdetectability Data	Sonar Lineup	Sonar Lineup	Sonar Lineup
12	ESM Contact Data	Target Fire Control Solution	Sonar Search Plan	Sonar Tracker/Cursor Audio
13	Sonar Tracker/Cursor Audio	Ship's Atmosphere	Sonar Tracker/Cursor Audio	Target Fire Control Solution
14	Active Sonar Lineup	Sonar Search Plan	Active Sonar Lineup	Ship's Atmosphere
15	Propulsion Plant Lineup	Visual Contact Data	PMFL Data	Potable Water Status
16	Ship's Atmosphere	Potable Water Status	Ship's Atmosphere	PMFL Data
17	PMFL Data	Sanitary Tank Status	ESM Contact Data	ESM Contact Data
18	Visual Contact Data	ESM Contact Data	Potable Water Status	Visual Contact Data
19	Potable Water Status	PMFL Data	Visual Contact Data	Active Sonar Lineup
20	Sanitary Tank Status	Active Sonar Lineup	Sanitary Tank Status	Sanitary Tank Status

APPENDIX E Results from Multivariate Analysis for Own Ship Parameters and Contact Management Cluster

Source	DV	Type III SS	df	Mean Square	F	Sig.
Participant Group	C01 [a]	803.098	3	267.699	10.359	.000
	C02 [e]	61.430	3	20.477	1.274	.283
	C08 [a]	1813.450	3	604.483	18.289	.000
	C14 [c]	466.602	3	155.534	9.513	.000
	C15 [e]	302.838	3	100.946	5.417	.001
	C16 [b]	410.182	3	136.727	7.004	.000
	C19 [d]	368.573	3	122.858	5.398	.001
Error	C01	13540.902	524	25.841		
	C08	17319.459	524	33.052		
	C14	8566.914	524	16.349		
	C15	9764.677	524	18.635		
	C16	10228.477	524	19.520		
	C19	11925.379	524	22.758		

[a] SOBCpre, SOBCpst, and SOAC significantly different from Expert Group
[b] SOBCpre and SOBCpst significantly different from Expert Group
[c] SOBCpst significantly different from Expert Group
[d] SOAC significantly different from Expert Group
[e] None significantly different from Expert Group

APPENDIX F Results from Multivariate Analysis for Ship System Status Cluster

Source	DV	Type III SS	df	Mean Square	F	Sig.
Participant Group	C06 [a]	773.77	3	257.92	10.23	0.00
	C09 [a]	144.73	3	48.24	3.51	0.02
	C11 [a]	50.76	3	16.92	1.01	0.39
	C13 [a]	208.19	3	69.40	5.60	0.00
Error	C06	13207.86	524	25.21		
	C09	7213.45	524	13.77		
	C11	8765.30	524	16.73		
	C13	6496.58	524	12.40		

[a] None significantly different from Expert Group

APPENDIX G Results from Multivariate Analysis for Equipment Lineup/Search Data Cluster

Source	DV	Type III SS	df	Mean Square	F	Sig.
Participant Group	C04 [a]	427.62	3	142.54	7.38	0.00
	C05 [a]	926.12	3	308.71	17.09	0.00
	C07 [a]	485.87	3	161.96	7.29	0.00
	C10 [b]	200.92	3	66.97	4.40	0.01
	C18 [c]	1258.96	3	419.65	21.98	0.00
Error	C04	10095.32	523	19.30		
	C05	9447.38	523	18.06		
	C07	11617.91	523	22.21		
	C10	7954.42	523	15.21		
	C18	9987.62	523	19.10		

[a] None significantly different from Expert Group
[b] SOBCpre significantly different from Expert Group
[c] SOAC significantly different from Expert Group

APPENDIX H Results from Multivariate Analysis for Sonar Tactical Displays Cluster

Source	DV	Type III SS	df	Mean Square	F	Sig.
Participant Group	C03 [a]	451.424	3	150.475	12.091	.000
	C12 [a]	97.034	3	32.345	1.634	.180
	C17 [b]	2464.951	3	821.650	44.870	.000
	C20 [c]	421.197	3	140.399	6.511	.000
Error	C03	6521.256	524	12.445		
	C12	10370.959	524	19.792		
	C17	9595.292	524	18.312		
	C20	11298.864	524	21.563		

[a] None significantly different from Expert Group
[b] SOBCpre and SOBCpst significantly different from Expert Group
[c] SOBCpre, SOBCpst, and SOAC significantly different from Expert Group

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14. ABSTRACT
It is increasingly being recognized that understanding expert knowledge structures associated with critical decision processes may facilitate Naval personnel performance. Towards this end, system developers and training researchers attempt to identify critical components of expert operator assessment and knowledge. Differing domains of practice rely to varying degrees on perceptual and conceptual knowledge. Perceptual knowledge is relied upon for recognizing critical cues in the environment whereas conceptual knowledge is used to interpret the meaning and importance of these cues. Via analyses of submariner knowledge for concepts related to responsibilities for the Officer of the Deck (OOD) task, this study examined how training may alter knowledge representation and priority of conceptual importance and how overlap in mental models may be due to amount of experience.

Continued

15. SUBJECT TERMS
mental models, submarine, cognitive organization, human factors, training, decision displays, card sorting

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14. Abstract (cont)

Eighty-three Naval Officers performed a card sorting and ranking task to indicate similarity and relative importance among 20 categories of information available on submarines in different operational environments. These submarine concepts consisted of types of information the submarine OOD would encounter while on watch, with the exception of tactics information. Participants were instructed to sort the cards into piles according to similarity and were not constrained by the number of piles they could create. Following the sorting task participants ranked the cards according to relative importance for four scenarios. They were instructed to create a single pile of cards ordered from the most important piece of submarine information to the least important. Data were collected from Submarine Officer Basic Course (SOBC) students pre and post course, Submarine Officer Advanced Course (SOAC) students, and Post Department Head submariners (PostDH).

Correlations between and among participant groups (SOBCpre, SOBCpst, SOAC, PostDH) revealed differences in cognitive organization of the submarine OOD concepts. Within group comparisons showed that the degree of mental model similarity was significantly greater for more experienced participants. When considering across group comparisons, analyses showed that the degree of across group mental model similarity was greatest for SOAC and SOBCpst. Moreover, SOAC students were in higher agreement with the expert composite model generated from Post DH submariners, and concept rankings varied as a function of experience.

In support of shared mental model theory and consistent with other studies of knowledge organization and the mental models of submariners, this investigation found that more experienced personnel view conceptual linkages more similarly and showed higher agreement with an expert model (Fiore, Fowlkes, Martin-Milham, & Oser, 2000). Conversely, the least experienced personnel see conceptual linkages less similarly, but, following training, these participants were found to view the conceptual linkages more similarly to the experienced personnel. From the standpoint of understanding the importance of particular concepts, significant differences between experienced and novice personnel were identified prior to, and following, training. These data highlight how participants vary in their understanding of the importance of these concepts